A NOVEL METHOD FOR SURVEYING LOW HEAD RIVERS

by

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Approved by ______________________________
Chairperson of Supervisory Committee

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Date ______________________________

THE OHIO STATEUNIVERSITY

ABSTRACT

A NOVEL METHOD FOR
SURVEYING LOW HEAD RIVERS
AND STREAMS

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Measuring the geometry and the flow in river channels is an area of great interest in hydraulic engineering. Data describing these physical parameters has practical value in predicting flood levels and river restoration designs. Traditional survey techniques for mapping river bathymetry and determining flows are time consuming, imprecise and costly. Acoustic Doppler technology has been used for measuring water velocity for the past 25 years. These systems have primarily been utilized to study the currents and wave patterns of oceans and estuaries.

Further advancements through the 1990's have led to acoustic Doppler profiling systems capable of obtaining high-resolution data in rivers and streams. Acoustic Doppler profiler systems are currently available for river and stream surveying, however very little attention has been given to the applications of this technology to shallow rivers and streams. The objectives of this study are to design a system capable of maximizing the

utility of acoustic Doppler technology in a low head river system, shakedown and implement this system in field, the assessment of the resulting data and make recommendations for data application (i.e. describe parameters able to be defined by the data), 4) Verify the validity of the data acquired from surveying low head rivers and streams, 5) Summarize the capabilities and limitations of implementing acoustic Doppler technology in low head bodies of water.

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Chapter 1

INTRODUCTION AND OBJECTIVES

Measuring the geometry and the flow in river channels is an area of great interest in hydraulic engineering. Data describing these physical parameters has practical value in predicting flood levels and in aiding river restoration designs. Traditional survey techniques for mapping river bathymetry (Brasington et al. 2000) and determining flows are time consuming, imprecise, and costly. Accordingly, these techniques were often done on a small number of cross sections to reduce the survey costs. With the advent of modern instrumentation, engineers can rapidly collect three-dimensional data sets with spatial and temporal resolutions superior to classic methods.

For many river systems, even basic hydraulic data are unavailable or are limited. The United States Geological Survey (USGS) maintains gaging stations to monitor flow and/or stage, but this is not feasible for all tributaries in a river network. Unfortunately data are unavailable for the vast majority of tributaries, especially in the smaller headwater streams. Therefore, the development of a surveying system to rapidly survey hydraulic and bathymetric features would be a cost effective asset for collecting these data sets.

The Ecological Engineer Group at OSU, in the Department of Civil and Environmental Engineering and Geodetic Science, has recently purchased a suite of sensors for use in river surveying. This paper details the development and implementation of a system intended to remedy the difficulties associated with surveying smaller-headwater streams. The method combines a differential Global Positioning System (herein referred to as GPS) to measure channel geometry and elevation and an acoustic Doppler profiler (ADP) to measure water velocities and depth to the bottom (river bed). Data can be collected in real time, allowing for simultaneous profiling of three-dimensional velocities and stream bathymetry, defined in a geo-referenced coordinate system. Both discharge (flow) and stage (water level) of the river can be derived using the measured channel geometry.

Chapter 2

BACKGROUND

Acoustic Doppler technology has been used for measuring water velocity for the past 25 years. These systems have primarily been utilized to study the currents and wave patterns of oceans and estuaries. In the late 1980's, acoustic Doppler technology was implemented on a moving vessel, principally for data acquisition in deep waters (greater than 4.0 m). Early acoustic Doppler instrumentation constrained the use of this technology to only water bodies of significant depth. However, in 1992 the development of broadband acoustic Doppler technology lent itself useful in profiling water bodies of significantly lowers depths (as shallow as 1.0 m). (Yorke et. al. 1992)

Further advancements through the 1990's have led to acoustic Doppler profiling systems capable of obtaining high-resolution data in rivers and streams (Yorke et. al. 1992). Acoustic Doppler profiler systems are currently available for river and stream surveying, however very little attention has been given to the applications of this technology to shallow rivers and streams. Further advancements in acoustic Doppler technology make it feasible to measure water levels less than 2 m.

Acoustic Doppler technology utilizes transducers to generate a narrow beam of sound that is projected through the water and reflects off suspended sediment, biological matter, or bubbles. The ADP unit measures the Doppler shift, which is essentially a change in wave frequency resulting from the reflection of the acoustic wave. This Doppler effect occurs whenever an observed "scatterer" is moving relative to an observer, in this case the ADP. From this Doppler shift, the ADP unit can resolve a velocity vector, specifying direction and magnitude.

The objectives of this study are to: 1) Design a system capable of maximizing the utility of acoustic Doppler technology in a low head river system. 2) Shakedown and implement this system in field. 3) Assess the resulting data and make recommendations for data application (i.e. describe parameters able to be defined by the data). 4) Verify the validity of the data acquired from surveying low head rivers and streams. and 5) Summarize the capabilities and limitations of implementing acoustic Doppler technology in low head bodies of water.

Chapter 3

METHODS AND MATERIALS

System Development

The system design was based upon the priorities established to qualitatively define the utility of a data acquisition system for use in low head rivers. The following system characteristics were identified as priorities:

1. Mobility in the field.

Typical survey methods involve mobilization over land to the river cross sections of interest, where land-based survey methods are used (i.e. ADP catamaran, or total station) for obtaining data. An increase in field mobility allows the researcher to maintain system operation in the water and navigate to areas of interest without having to relocate by land. This eliminates system set-up and disassembly required for land based relocation. Due to the inaccessibility of potential study locations, a light, mobile system is absolutely necessary to decrease the hassle that accompanies field mobilization.

2. Ease of set-up in the field

Once at the study location, the system will require setup. Typically, a system, with capabilities similar to those proposed in this study, requires complicated integration of many components, which can be troublesome. Increasing the ease of set-up will decrease the time and materials needed to implement the system in the field. Accordingly, there will be an increase in daylight time dedicated to data acquisition, which will result in relatively large quantities of data per day.

3. Non-intrusive to flow regime

In measuring river flow characteristics, the need for a system that does not disrupt the streamlines is important. A river survey intended to describe the physical characteristics of a river environment cannot be considered valid if the measurement interferes with the variables being measured.

4. Potential for parameter integration

Collecting a time series of data, measuring varying parameters simultaneously, becomes a very powerful tool. This type of system must support the use of multiple instruments simultaneously.

System Design

The heart of the system is based on the Sontek Inc. River Surveyor ADP. This system includes windows-based data acquisition and post-processing software. GPS position data can be recorded directly by the ADP via a PC serial port. The integration of GPS with the ADP, allows for bathymetric and water current data to be linked to global positions. Additionally, the GPS logs elevation data internally which can be referenced to water elevation.

A canoe was chosen as the vessel or platform used to deploy the GPS-ADP system in the field. This was suitable for two reasons: 1) canoes generally have a wide base, resulting in relatively high displacement out of the water. This allows for the vessel to navigate through areas of shallow depths without disturbing the river bed, and 2) two individuals can occupy the vessel at one time, allowing for one occupant to maintain the ADP system, while the other navigates.

The system was assembled in two phases. The first phase consisted of developing mounts for the data acquisition equipment, namely the GPS and ADP. An aluminum mount was machined such that it could be attached to the center cross section of the canoe. This mount supports an aluminum pole of 3.5 ft in height, the GPS receiver is mounted to the top with a threaded connection, and the ADP receiver is attached to the bottom of the pole with hose clamps. This setup is pictured in Figure 1.

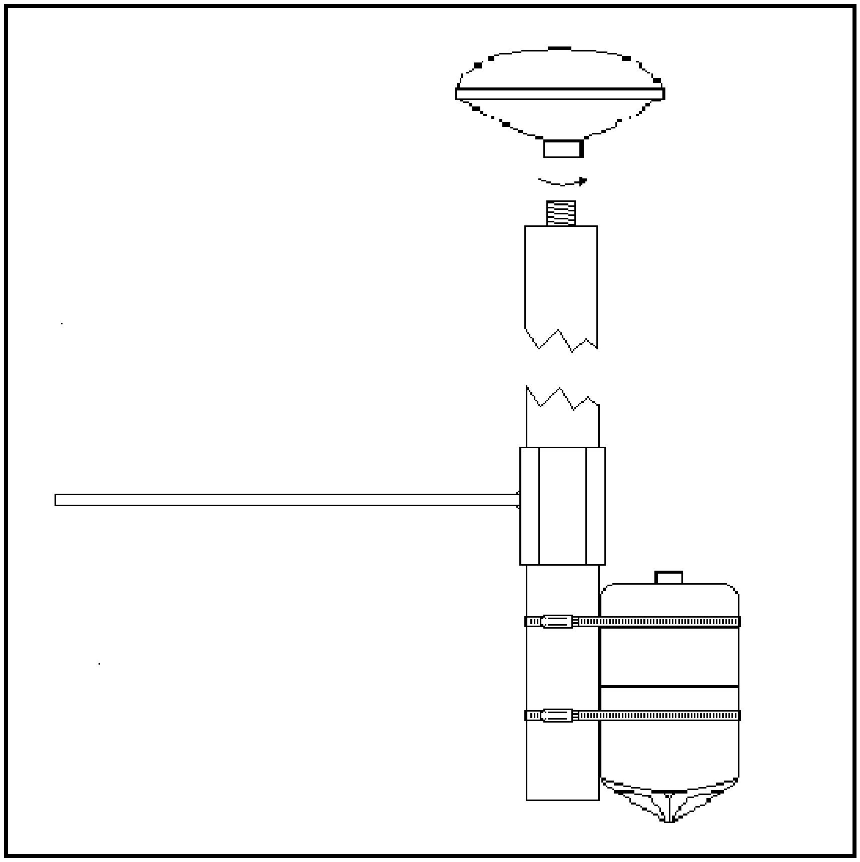

Figure 1. Aluminum Mount for GPS and ADP Sensors

The ADP was attached to the bottom of the pole such that the sensors were submerged roughly 3 inches below the still water level. It is necessary to measure the distance from the reference point on the GPS receiver to the location of the ADP sensors submerged underwater. This distance is needed to process the elevation of the riverbed. The GPS unit measures the elevation of the GPS receiver above mean sea level (amsl), and therefore the distance between the GPS and ADP is necessary to relate the elevation data to the ADP bathymetry data. The ADP measurements are calculated relative to the sensors; the River Surveyor program performs all the necessary calculations to account for the vessel velocity, vessel direction and vessel tilt angle.

The second phase involved the design of a means of system mobilization. Rowing, which is the typical method used in canoeing is both labor intensive and disruptive to the flow regime. Also, rowing does not give the system operators the ability to monitor the status of the system, ensuring the integrity of the data. To alleviate this a trolling motor was mounted on the port-side, near the stern. The relative position of the ADP unit is starboard-side towards the bow, this ensures that the motor will not disrupt the flow near and around the sensor. Figure 2 shows a graphical representation of the system components as setup for use in the field.

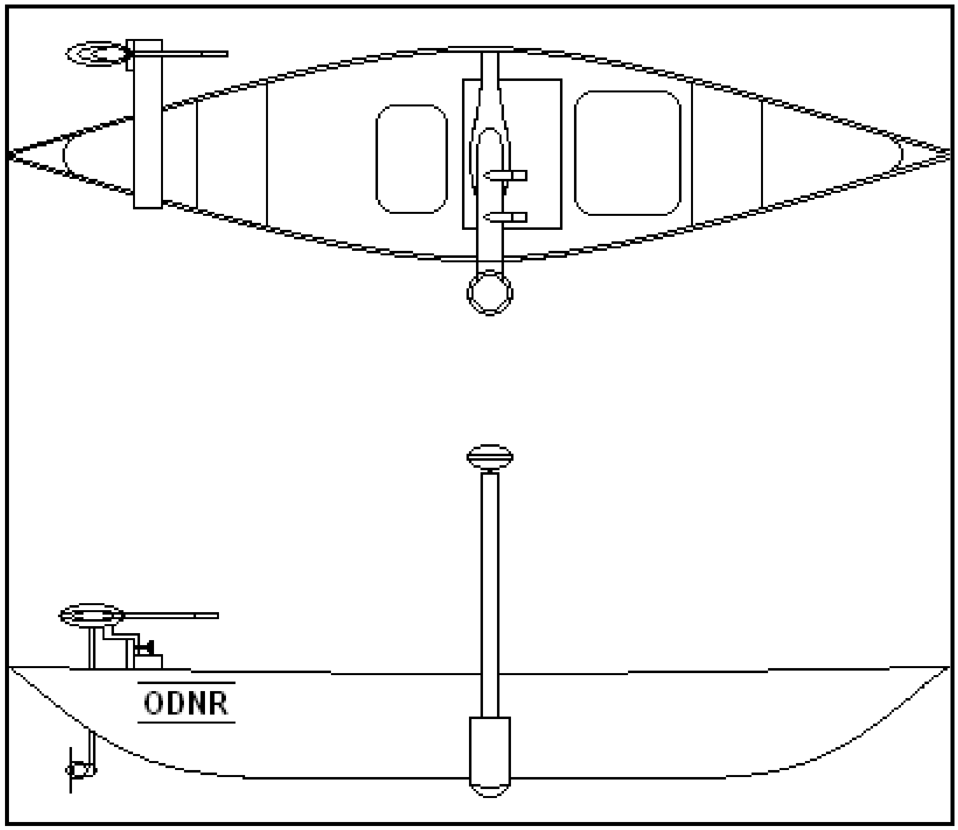

Figure 2. Schematic of canoe setup as used in the field

Power consumption was a driving constraint in choosing an acceptable motor unit. The Minn-Kota Endura 30 outboard motor was chosen because it required the least amount of power for operation, this results in increased battery life, and thus longer sampling events. Speed is not an issue, in fact a slower moving vessel is optimal for data collection; this will result in higher data resolution, for a given sampling frequency.

The motor was attached to the canoe using a custom-made motor mount, designed to optimize system efficiency. The motor mount clamps onto the side lips of the left and right gunnels, the mount extends roughly a 1.5 feet out from the port-side (Figure 3). This extension is equipped with a mounting platform allowing the outboard motor to be clamped onto the mount. Both the motor and the motor mount are connected with clamps, for quick assembly in the field.

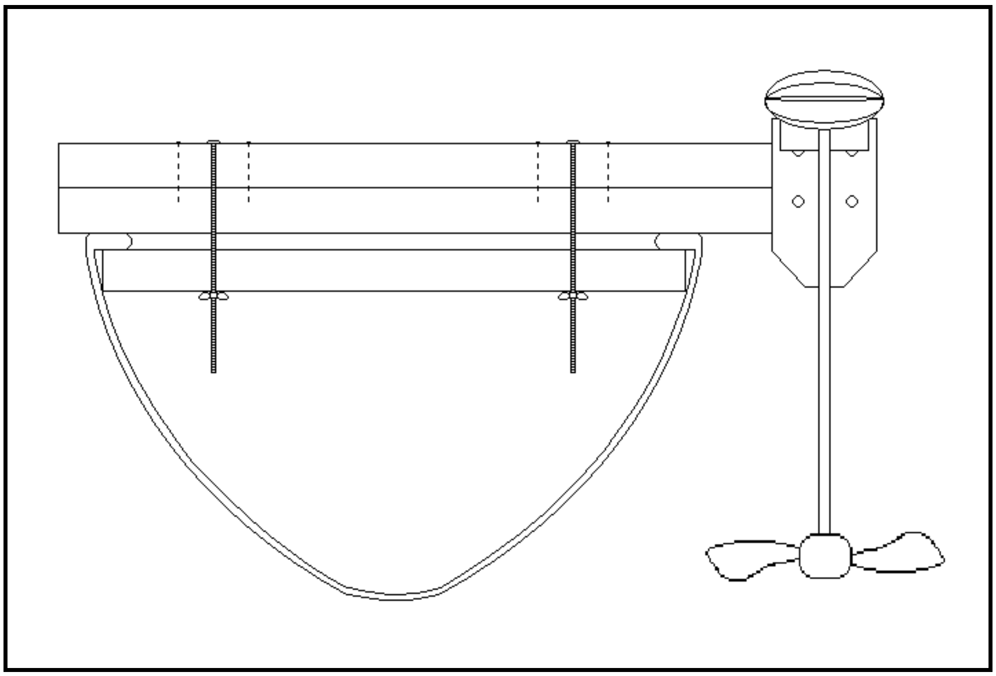

Figure 3. Motor Mount Cross Section

A 12 volt, deep cycle, marine battery was used to power the canoe. The battery provides power to the onboard computer and the trolling motor. A power inverter connects the computer to the battery. This component serves three purposes. First, the inverter converts the direct current (DC) from the battery to an alternating current (AC), for powering the computer, second, to power the ADP. Third, the inverter is equipped with a fuse, which protects the computer from potential power surges. The data collection system of the GPS was powered by internal batteries specific to the respective unit. Both the GPS and the ADP were connected directly to the computer. The electrical system is detailed in Figure 4.

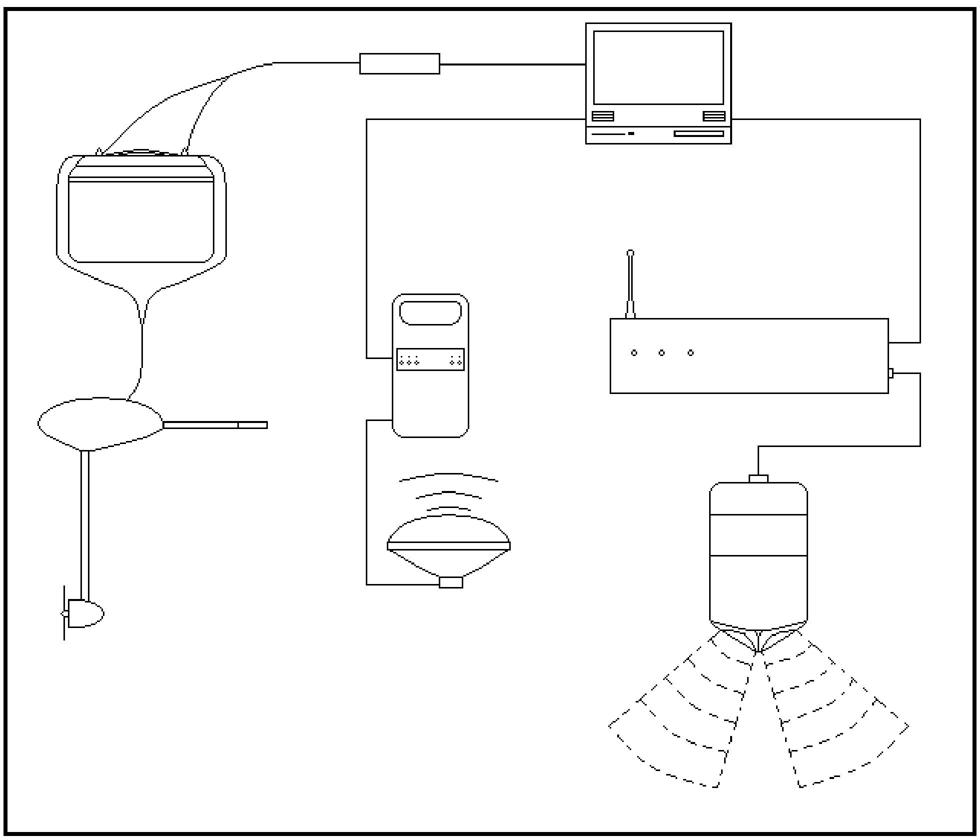

Figure 4. Electrical System Layout

The assembled system collects real time data via the onboard laptop, and also allows the user to monitor the system, making sure that the

ADP and the GPS are interfaced properly. The collection of data describing the physical properties of rivers has typically involved a considerable investment of time and resources (Gard and Ballard, 2003). Technological innovation has provided opportunities to reduce the time and cost of data acquisition in rivers and streams. This method allows for large quantities of data to be obtained with relatively little time and monetary inputs. The system itself requires only upfront equipment costs; once the equipment has been obtained the system is a low maintenance-long term solution to the expensive and time-consuming survey methods currently used.

Field Testing

The second aspect of this study involved the implementation and testing of this system in the field. The USGS gaging stations offer an opportunity to test the system's accuracy in estimating river discharge. The ADP unit creates binned velocity profiles, averaged over 5 second intervals. From this data, the ADP processing software, RiverSurveyor, estimates flow rate by calculating a velocity profile based on the measured water velocity. This calculation is governed by the following power law:

$$\frac{u}{u_*} = 9.5 * \left(\frac{y}{h}\right)^{\frac{1}{6}}$$

where y is the elevation measured from the bed, h is the bed depth, u is the velocity at elevation y, and u_* is the shear velocity (Sontek 2003). This velocity profile is integrated across horizontal bins specified to encompass one transect. This integration gives a net flow rate for that set of averaged values.

The ADP used in this surveying system only profiles water velocities ranging from 0.6 to 6.0 m (2.0 – 20 ft) below the elevation of the ADP sensors (Sontek 2003). These constraints limit the accuracy of velocity data in low head rivers and streams.

Testing Locations

In order to validate the GPS-ADP, we surveyed three of the United States Geological Survey's (USGS) stream monitoring stations in Ohio, which collect real-time flow rates and water stage. Figures 5 - 8 detail the locations of the three stations used for this study.

1. Tymochtee Creek; Crawford, Ohio; Wyandot County

   <u>Location</u> - 40°55'22", 83°21'56", on the right bank at downstream side of bridge on State Highway 199, 0.4 mi southwest of Crawford, 1.5 mi downstream from Lick Run, 2.7 mi upstream from Little Tymochtee Creek and 3 mi southeast of Carey.

- Period of Record - June 1964 to current year.

- Drainage Area - 229 mi^2

- Datum of gage is 785.86 ft. AMSL (USGS)

2. Sandusky River near Upper Sandusky, Ohio, Wyandot County

   <u>Location</u> - Lat 40°51''02", Long 83°15'23, on left bank at downstream side of county road bridge, 0.7 mi. downstream from unnamed right bank tributary, 0.8 mi. upstream from Rock Run, and 2.0 mi. northeast of Upper Sandusky.

   - Period of Record - 1922-35, 1938-82, Nov. 1 2001 to present.

   - Drainage Area - 298 mi^2

   - Datum of gauge is 792.25 ft. above AMSL (USGS)

3. Olentangy River near Worthington, OH

   <u>Location</u> - Lat 40°06'37", long 83°01'55", on left bank, 350 ft downstream of I-270 bridge, 1.5 miles northwest of Worthington, OH, and 2.8 miles upstream from Rush Run.

   -Drainage Area - 497 mi^2.

   -Datum of gage is 743.20 ft AMSL (USGS)

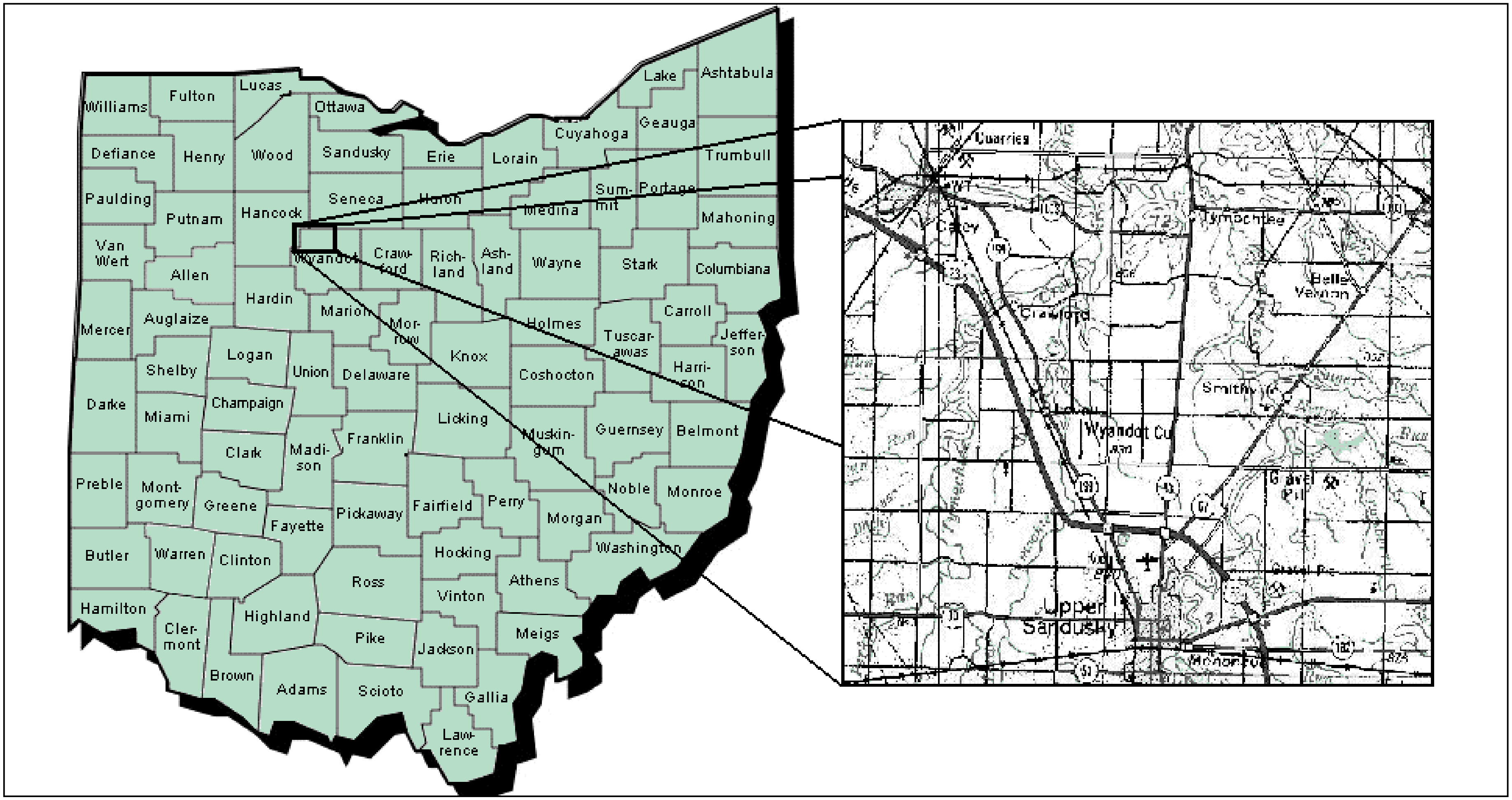

Figure 5. Regional Locator Map for the Tymochtee Creek and the Sandusky River

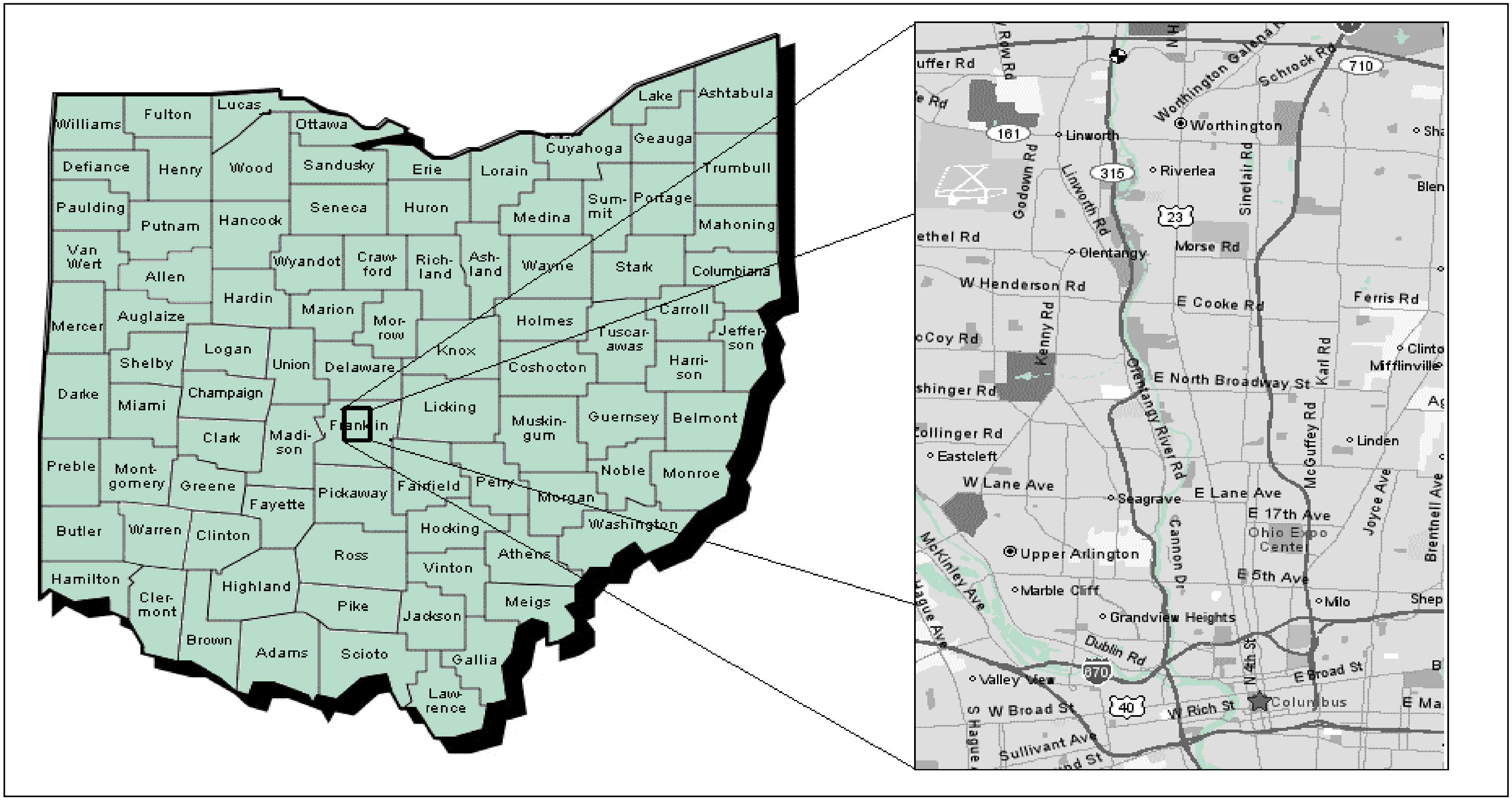

Figure 6. Regional Locator Map for the Olentangy River

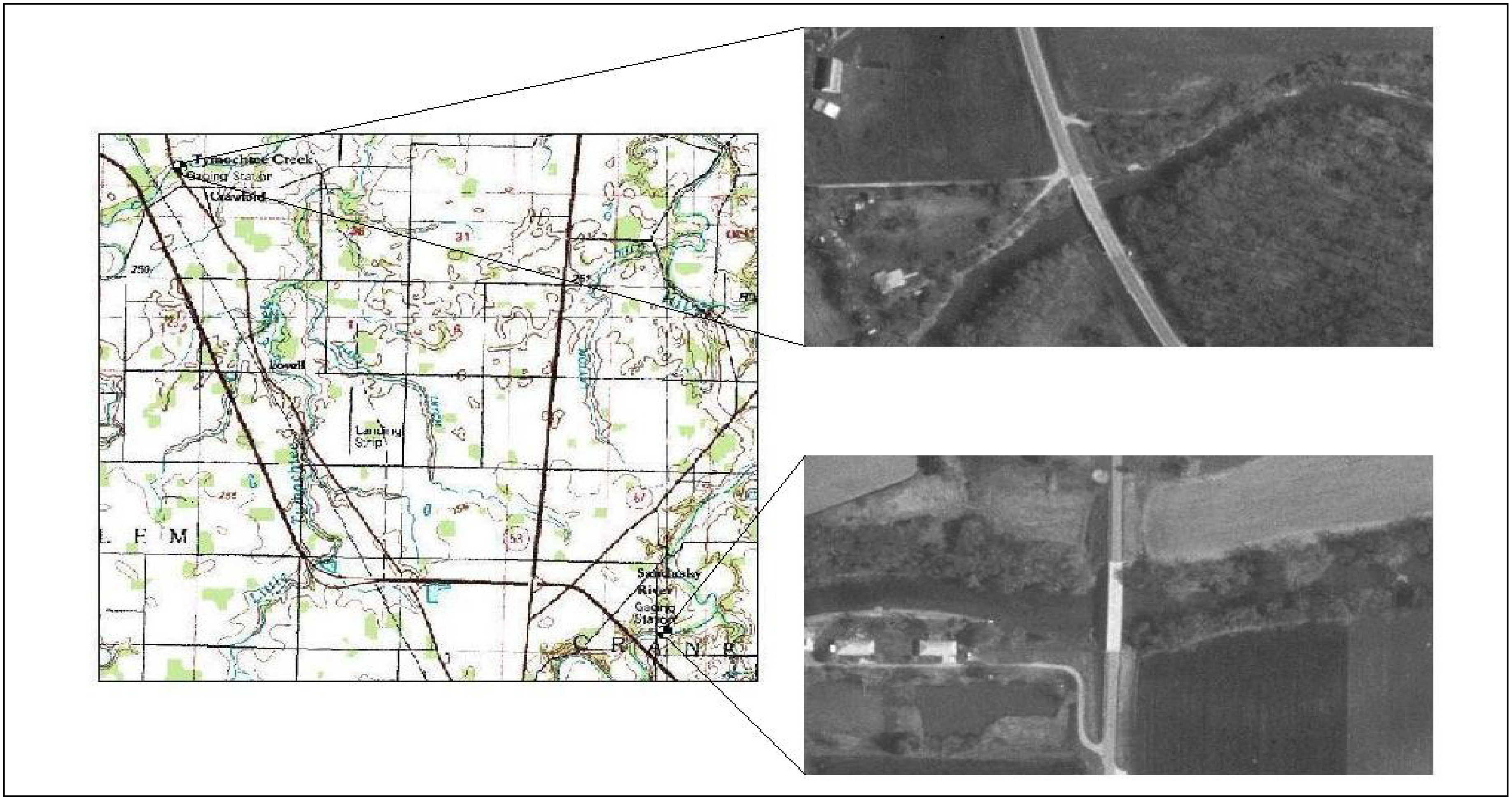

Figure 7. Tymochtee Creek and the Sandusky River Reach Scale Map with Site Aerials

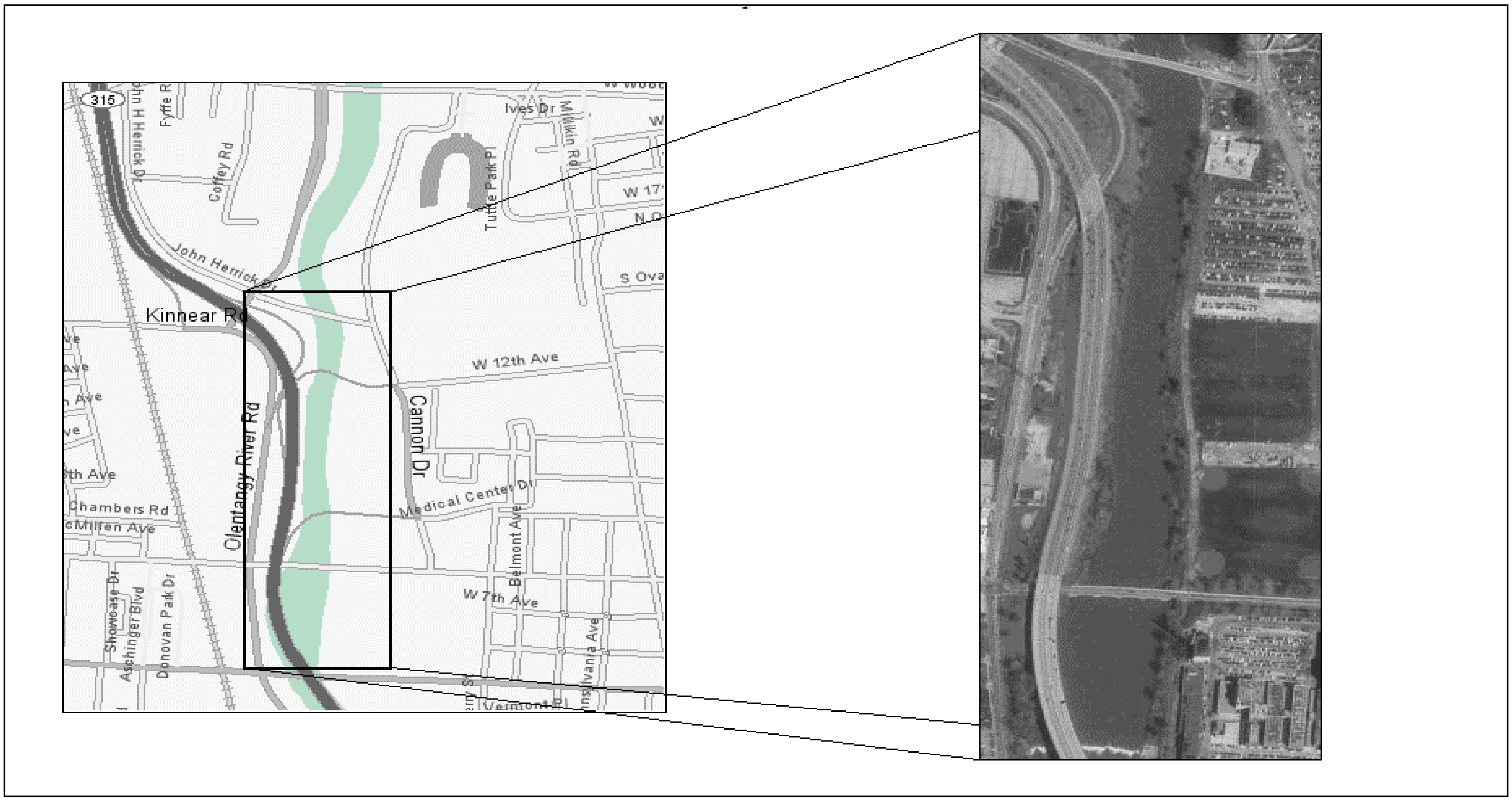

Figure 8. Olentangy River Reach Scale Map with Site Aerial

Chapter 4

RESULTS

The gaging station results were obtained from the USGS offline information database. These data were used as a reference to judge the accuracy of the system's flow rate estimates. The following section details the results at each particular sampling location.

Tymochtee Creek Results

Being the first field-scale use of the system, the outing at the Tymochtee Creek gaging station served as the system shakedown. This is a relatively small stream, and the survey was limited to a reach scale study in the area around the Tymochtee gaging station. The GPS survey controller would not remain activated and it was unable to be configured to the computer. All other equipment was set up as planned. The survey consisted of 15 minutes of equipment setup and configuration, followed by a 45-minute river survey. This event yielded roughly 600 data points for bathymetry relative to the sensor, and water velocity. Due to the relatively shallow stage, the acoustic Doppler equipment experienced periods of "blanking", in which the data transmitted to the computer was not valid and had to be discarded. This situation was limited to areas near the stream bank, where the water level was relatively shallow (about 0.2 m), or riffle zones, which are characteristically shallow.

Cross-sectional figures were generated for transects performed at the Tymochtee Creek gaging station. It should be noted that data near and around the stream banks was not valid, and therefore an assumed bank slope of 45 degrees was used to generalize the cross-sections. Based on qualitative observations of this river reach, this assumption is adequate for this demonstration. A sample cross section is presented in Figure 9. A complete compilation of the cross sections from the Tymochtee River is presented in Appendix A.

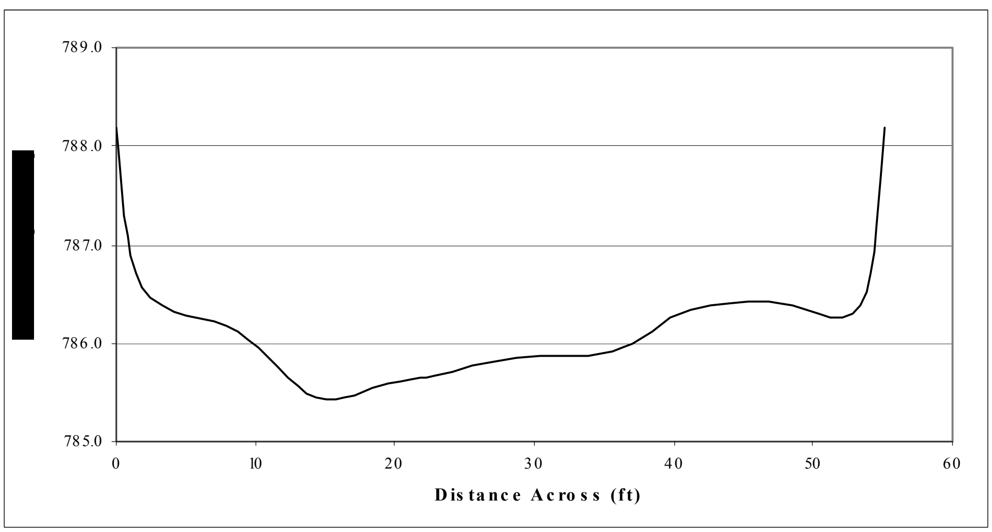

Figure 9. Tymochtee Sample Cross Section

The data used to generate the figures showing the Tymochtee Creek cross sections are presented in Appendix A. As previously stated, the

Tymochtee Creek sampling even consisted of roughly 600 data points, the data presented in these tables represents only the portion of the data used to generate the corresponding figures.

The other aspect of the data collection dealt with the verification of discharge calculated by the ADP and the accompanying software. The observed discharges, as calculated by the RiverSurveyor software, are presented in Table 1.

Table 1. Tymochtee Creek Discharge Summary

Profile #	Profile Range[a]	Actual Discharge[b] (ft3/sec)	ADP Calculated Discharge (ft3/sec)	Measured Discharge[c]	Estimated Discharge[d]	Percent Error
1	75-96	43	109.49	30.10%	69.90%	154.60%
2	98-118	43	10.6	26.90%	73.10%	-75.40%
3	125-142	43	127.15	32.50%	67.50%	195.70%
4	164-177	43	137.75	27.80%	72.20%	220.30%
5	192-206	43	17.66	57.90%	42.10%	-58.90%

a = Details the profile numbers composing the cross section
b = Discharge reported by the USGS gaging station
c = Discharge measured directly by the ADP
d = Discharge calculated to accommodate "blanking" areas and river banks

Table 1 also compares the calculated discharge to the discharge reported by the USGS. The average error associated with this set of profiles is 141%. There appears to be no apparent consistency in the values reported by the system. This error can most likely be attributed to very low-resolution velocity measurements, which may represent areas of higher velocity than seen in other regions of the cross section. Based on the low percentages of measure discharge, it is also clear that a minority of discharge data was actually observed by the ADP. This implies that most of the discharge was calculated by the post-processing software, and was based on a relatively small amount of actual data. As previously described, the RiverSurveyor program integrates the flow rate by estimating the velocity distribution for a binned cross-sectional area, this is the failing of the ADP in regions of relatively shallow waters (0-0.6 m or 0-2.0 ft). The system calculates velocities based on the observed measurements, however, the limitations of the ADP used in this system constrain the number of velocity measurements obtained and thus compromise the integrity of the discharge estimates.

Sandusky River Results

The gaging station in the Sandusky River, near Upper Sandusky, was situated in an area of shallow water, and thus limited the system's use in this river. Even the deepest sections of this river reach were within the 'blanking' limits of the ADP. As a result no good measurements were obtained here. Based on observations of this area, it was clear that the river stretch consisted of turbulent waters with higher velocities than those seen near the Tymochtee Creek gaging station. Riffle zones were also common in this reach of the Sandusky River around the area of the gaging station.

Olentangy River Results

The results of the shallow water testing at the Tymochtee Creek and the Sandusky River were limited by the specifications of the ADP. Further testing was necessary to determine system effectiveness. The Olentangy River essentially flows through the western portion of the Ohio State University. This particular stretch of river was chosen as the site for continued system testing. Using flow data from a USGS gaging station in Worthington, a suburb of Columbus located roughly 5 miles upstream of the Ohio State University, flow rates could be estimated for the stretch of river adjacent to the university.

The survey was conducted on approximately a 0.75 mile river stretch between the Ohio State University and the 5th Avenue dam. Thirteen cross sections were performed throughout this stretch of river. Data inspection clearly showed that the system was more suited to operate in this type of deeper river environment. There was no significant "blanking" in any of these data sets.

Data near and around the riverbanks were assumed to be sloped at the 45-degree angle, which is consistent with the assumptions made at the Tymochtee Creek gaging station. Figure 10 is an example of the cross sections obtained for the Olentangy River.

The data used to generate the figures showing the Olentangy River cross sections are presented in Appendix B. A complete collection of cross sectional figures is also included in Appendix B. The Olentangy River sampling event consisted of 1090 data points, the data presented in these tables represents only the portion of the data used to generate the corresponding cross sectional figures.

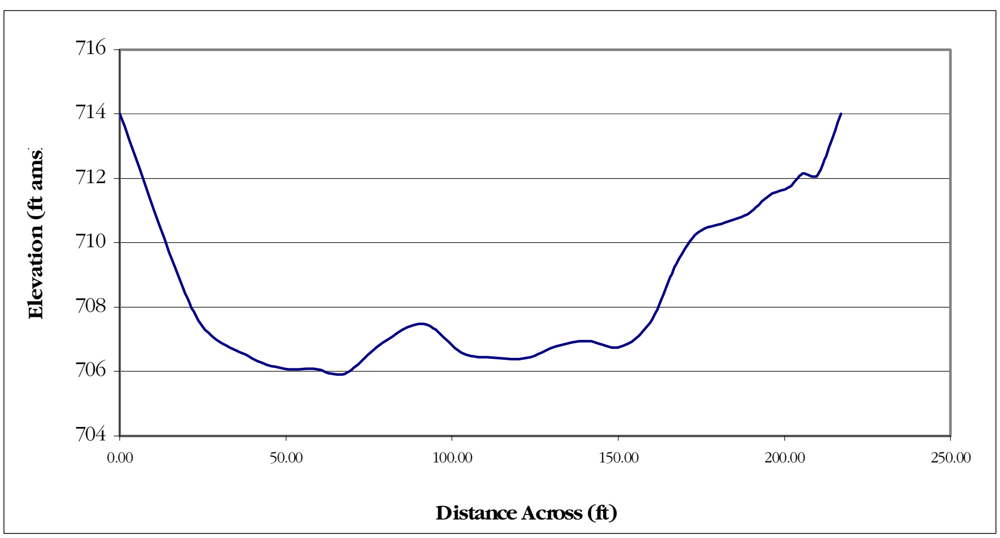

Figure 10. Olentangy Sample Cross Section

Flow rates calculated by the RiverSurveyor software, are presented in Table 2. The results of this survey were far more accurate that those seen at the Tymochtee Creek. Average error associated with the Olentangy River data set is 35%, which represents a four-fold increase in accuracy, when compared to the Tymochtee Creek results. This 35% error, however, is also relatively high, and again, there is no obvious trend in the error seen in these results. Six of the thirteen cross-sections have a negative error, indicating that the discharge calculation was less than that seen at the USGS gaging station. These discharge calculations seem to be randomly distributed. In an attempt to explain some of these inconsistencies, an error analysis was performed.

Table 2. Olentangy River Discharge Summary

Profile #	Profile Range[a]	Actual Discharge[b] (ft3/sec)	ADP Calculated Discharge (ft3/sec)	Measured Discharge[c]	Estimated Discharge[d]	Percent Error
1	229-270	189.08	116.56	50.40%	49.60%	-38.36%
2	284-316	189.08	187.20	61.70%	38.30%	-1.00%
3	319-349	189.08	275.49	60.80%	39.20%	45.70%
4	375-412	189.08	236.64	63.50%	36.50%	25.15%
5	414-443	189.08	346.13	66.70%	33.30%	83.06%
6	468-494	189.08	233.11	72.20%	27.80%	23.28%
7	525-545	189.08	286.09	70.00%	30.00%	51.30%
8	546-566	189.08	141.28	71.80%	28.20%	-25.28%
9	662-686	189.08	201.32	69.60%	30.40%	6.47%
10	740-766	189.08	187.20	71.80%	28.20%	-1.00%
11	862-872	189.08	28.26	86.50%	13.50%	-85.06%

12	878-890	189.08	81.24	73.00%	27.00%	-57.04%
13	915-940	189.08	176.60	44.90%	55.10%	-6.60%

a = Details the profile numbers composing the cross section
b = Discharge reported by the USGS gaging station
c = Discharge measured directly by the ADP
d = Discharge calculated to accommodate "blanking" areas and river banks

Error Analysis

The two primary variable from site to site were river width and depth. (Table 3) In an attempt to describe the correlation of these two parameters, each was plotted against percent error (Figures 11 and 12). Figures 11 and 12 show trends that suggest percent error is inversely related to both maximum cross sectional depth and cross sectional distance.

An increased cross sectional distance would imply a longer stretch for data collection, resulting in more data for that particular cross section. It makes sense that this increase in data would result in a more accurate measurement. Essentially the error of the system is dependent on the specifications of the acoustic Doppler technology used. In this case, binned velocity data cannot be collected until a depth of 0.6 m (roughly 2 ft.), thus it is not surprising that discharge estimates are not accurate at lower depths.

In regards to the correlation between cross-sectional distance and accuracy, the same idea holds true. In effect, a deeper cross section will allow for the development of a well-defined flow regime, resulting from an increase in velocity profile bins.

Table 3. Error Analysis For the Set of Combined Cross Sections

Profile #	Profile Range[a]	Actual Discharge[b] (ft3/sec)	ADP Calculated Discharge (ft3/sec)	Measured Discharge[c]	Estimated Discharge[d]	Percent Error	Distance	Depth
1 - OR	229-270	189.08	116.56	50.40%	49.60%	38.36%	463.61	5.25
2 - OR	284-316	189.08	187.20	61.70%	38.30%	1.00%	439.98	5.84
3 - OR	319-349	189.08	275.49	60.80%	39.20%	45.70%	358.61	5.91
4 - OR	375-412	189.08	236.64	63.50%	36.50%	25.15%	401.92	6.79
5 - OR	414-443	189.08	346.13	66.70%	33.30%	83.06%	328.43	8.56
6 - OR	468-494	189.08	233.11	72.20%	27.80%	23.28%	265.76	6.82
7 - OR	525-545	189.08	286.09	70.00%	30.00%	51.30%	207.69	8.56
8 - OR	546-566	189.08	141.28	71.80%	28.20%	25.28%	199.48	8.37
9 - OR	662-686	189.08	201.32	69.60%	30.40%	6.47%	199.81	8.07
10 - OR	740-766	189.08	187.20	71.80%	28.20%	1.00%	242.79	7.64
11 - OR	862-872	189.08	28.26	86.50%	13.50%	85.06%	98.76	7.81
12 - OR	878-890	189.08	81.24	73.00%	27.00%	57.04%	78.42	7.48
13 - OR	915-940	189.08	176.60	44.90%	55.10%	6.60%	247.06	4.36
1 - TC	75-96	43.00	109.49	30.10%	69.90%	154.60%	105.32	2.59
2 - TC	98-118	43.00	10.6	26.90%	73.10%	75.40%	106.96	1.87
3 - TC	125-142	43.00	127.15	32.50%	67.50%	195.70%	82.03	2.72
4 - TC	164-177	43.00	137.75	27.80%	72.20%	220.30%	100.40	2.30
5 - TC	192-206	43.00	17.66	57.90%	42.10%	58.90%	79.40	2.40

OR = Olentangy River

TC = Tymochtee Creek

a = Details the profile numbers composing the cross section

b = Discharge reported by the USGS gaging station

c = Discharge measured directly by the ADP

d = Discharge calculated to accommodate "blanking" areas and river banks

e = Cross sectional distance

f = Maximum depth seen in the cross section

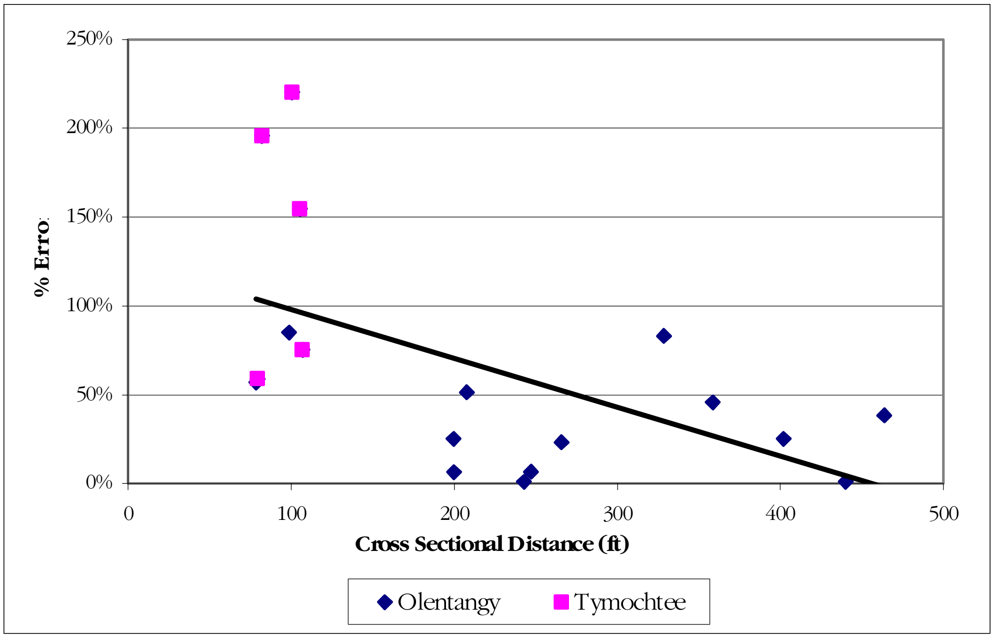

Figure 11. Cross Sectional Distance v. Percent Error

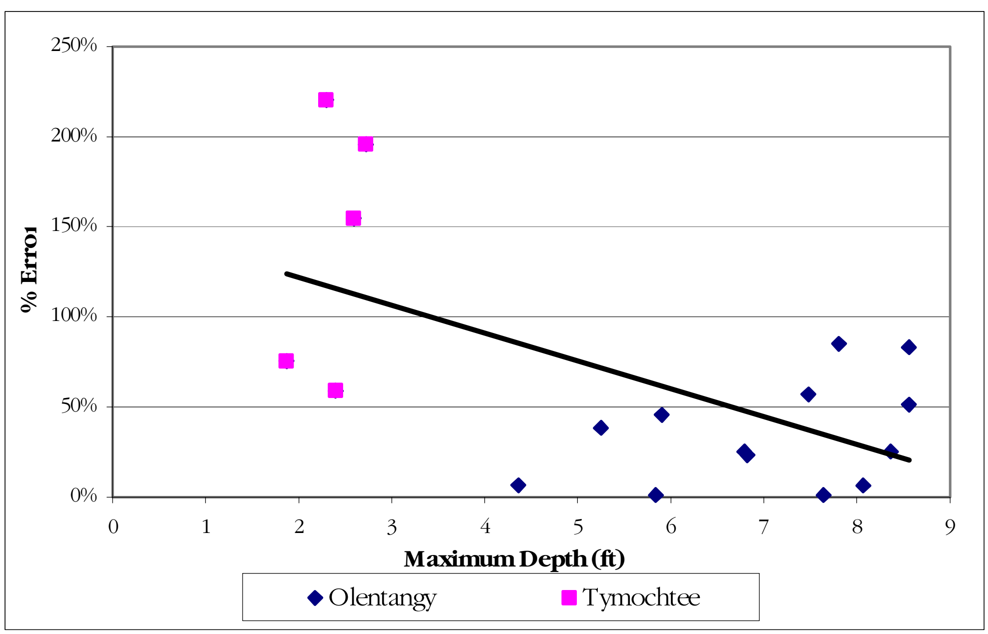

Figure 12. Maximum Cross Sectional Depth v. Percent Error

These trends are further substantiated in Figure 13, which shows the relationship between percent error and the percent of discharge actually measured by the ADP. It becomes clear that the percent error of discharge becomes less as the percent of measured discharge increases.

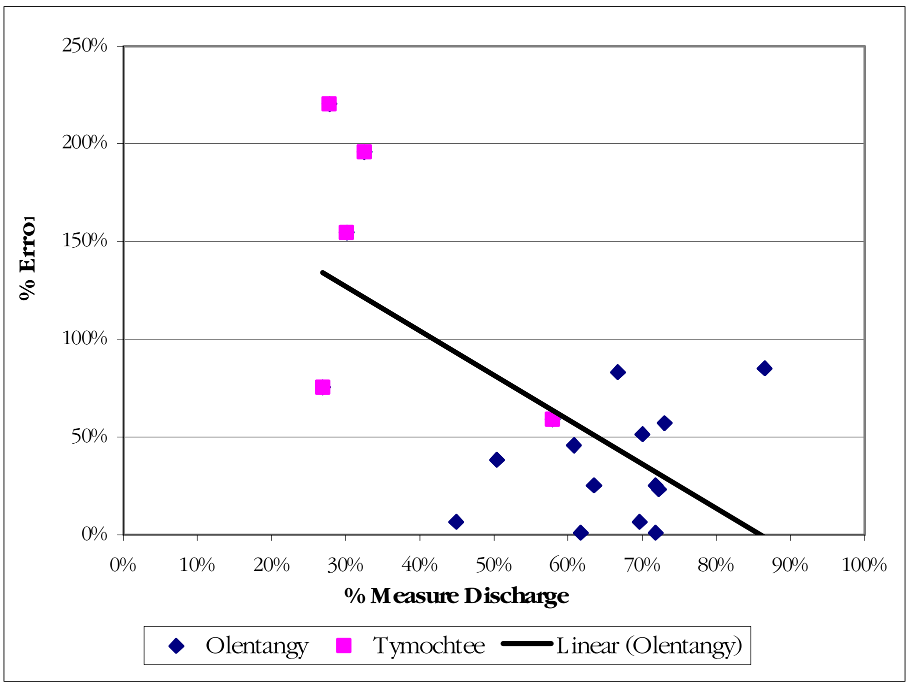

Figure 13. Percent Measured Discharge v. Percent Error

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

In conclusion, the limitations of the system are dependent on the limitations of the acoustic Doppler technology used. In this case, the Sontek RiverSurveyor ADP was specified to function properly in water depths greater than 0.2 m (roughly 0.5 ft). Unfortunately, two of the three gaging stations were located near river reaches of relatively shallow stage. This resulted in significant "blanking" which yielded large data gaps. The Sandusky River was so shallow that the system could not function. The Tymochtee Creek was shallow enough to generate discharge estimates with significant error and variability.

Further testing in the Olentangy River resulted in more accurate discharge estimates. However, even these results were relatively high in error and variability. The correlation between increased data per cross section and the resulting accuracy were clearly evident. This leads to the following conclusions regarding the implementation of this system in the field.

First, the system, with its current components, would most likely operate well in larger, deeper river systems with relatively high discharge. Secondly, the current system, utilizing an ADP more capable of operating in shallow waters, would most likely yield results with less error. Further testing of this system is recommended for both situations.

There is a chance that the ADP used in the current system is faulty. A deep water sampling event with the current system is necessary to determine whether the ADP unit is faulty, or the error seen in this study is doe to the relatively shallow sampling locations. Also, continued system development in low head streams, like the Tymochtee Creek and the Sandusky River, is recommended with acoustic Doppler technology more capable of data collection in shallow waters.

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